Akindeji and Ewim
Bulletin of the National Research Centre (2023) 47:75
https://doi.org/10.1186/s42269-023-01053-6

Bulletin of the National Research Centre

RESEARCH

Open Access

Economic and environmental analysis of a grid-connected hybrid power system for a University Campus

Kayode Timothy Akindeji[1] and Daniel Raphael Ejike Ewim[2*]

Abstract

Background The generation of clean and affordable energy by 2030 is a challenging task, necessitating the integration of renewable energy sources to reduce greenhouse gas emissions associated with coal, crude oil, and natural gas. This study examines the optimization and performance analysis of a hybrid microgrid for a university campus as a potential solution to achieve this goal. The primary objective is to decrease the cost of energy and reduce CO_2 emissions on the campus using a hybrid approach.

Results The Howard college campus of the University of KwaZulu Natal (UKZN) was used as a case study, with meteorological data obtained from NASA and real hourly electrical load data for 2019 from the university smart meters. HOMER, an optimization software, was employed to model and simulate the case study. The results demonstrated significant savings of R15.7 million (approximately $ 820 000) in annual utility bills, a 51% reduction in CO_2 emissions, a return on investment of 20%, and a payback period of 4 years.

Conclusion The study's findings suggest that universities can become self-sustaining during load shedding periods, as recently experienced in South Africa. The implementation of a hybrid microgrid system on a university campus offers considerable economic and environmental benefits, providing a potential blueprint for other large institutions seeking to achieve similar sustainability goals.

Keywords Hybrid microgrid, University campus, Renewable energy sources, Greenhouse gas emissions, Cost of energy, CO_2 reduction, Optimization, HOMER software, Load shedding, Sustainability

Background

A university campus serves as an excellent setting to model a microgrid, given the close proximity of various structures like dormitories, administrative buildings, lecture halls, labs, and athletic facilities, as well as a significant student population. These elements make campuses akin to small cities or towns. Implementing a microgrid within a college setting can help achieve various goals, including education, research, cost reduction, and lowering emissions. With numerous daily activities, such as machinery in labs, heating and cooling systems, and lighting, energy consumption on campuses can be substantial. Generally, these campuses rely on national power grids, which utilize fossil fuels like coal, natural gas, and oil, ultimately contributing to greenhouse gas emissions (Tu et al. 2015; Elenkova et al. 2017; Leal Filho et al. 2019; Vourdoubas 2019). In 2015, the United Nations established a set of 17 objectives, known as the Sustainable Development Goals (SDGs), with a target completion date of 2030. The primary focus of one of these goals (SDG 7) is to guarantee universal access to dependable, affordable, contemporary, and eco-friendly energy by the

*Correspondence:
Daniel Raphael Ejike Ewim
daniel.ewim@yahoo.com
[1] Department of Electrical Power Engineering, Durban University of Technology, Durban 4000, South Africa
[2] Department of Mechanical Engineering, Durban University of Technology, Durban 4000, South Africa

© The Author(s) 2023. **Open Access** This article is licensed under a Creative Commons Attribution 4.0 International License, which permits use, sharing, adaptation, distribution and reproduction in any medium or format, as long as you give appropriate credit to the original author(s) and the source, provide a link to the Creative Commons licence, and indicate if changes were made. The images or other third party material in this article are included in the article's Creative Commons licence, unless indicated otherwise in a credit line to the material. If material is not included in the article's Creative Commons licence and your intended use is not permitted by statutory regulation or exceeds the permitted use, you will need to obtain permission directly from the copyright holder. To view a copy of this licence, visit http://creativecommons.org/licenses/by/4.0/.

year 2030 (Rebelatto et al. 2019). As a result, higher education institutions ought to promote sustainable energy through academic inquiry, sharing essential information, raising awareness both within and beyond their institutions, and by designing and implementing sustainable energy models on their campuses (Dehghanmongabadi and Hoşkara 2018; Salvia et al. 2020). According to Tu et al. (2015), American universities are promoting the idea of sustainability among their students, faculty, staff, and the community. Similarly, universities worldwide are implementing sustainability schemes for their short- and long-term benefit (Hasapis et al. 2017). Some universities have also reviewed their energy policies and explored different energy resources to improve energy efficiency on their campuses (Makkonen et al. 2013). In the past decade, higher education institutions globally have funded renewable energy systems (RESs) to reduce energy demand and greenhouse gas (GHG) emissions in line with the Nearly Zero Energy Buildings (NZEB) concept. This has led to the implementation of microgrids on university campuses. Figure 1 in the article shows an installation of solar photovoltaic (PV) panels on the roof of a building at the Durban University of Technology (DUT), Steve Biko campus. The installation comprises a 5 kW inverter and 48 V, 50 AH lithium-ion battery (SDA10-4850). The system is connected to the grid and mainly used for practical experiments and to provide lighting in the offices during load shedding. College campuses can serve as experimental grounds for the development, testing, and deployment of advanced technologies related to intelligent energy systems through on-campus research initiatives. As a result, higher education institutions can act as ideal examples for decreasing fossil fuel consumption and enhancing energy management through the investigation, advancement, and integrated implementation of energy-saving solution (Elenkova et al. 2017; Rebelatto et al. 2019; Hadiyanto et al. 2018). Higher education institutions face various challenges that may hinder the expansion of microgrids, including environmental, technical, and financial limitations. However, the implementation of a microgrid within a college setting is not only technically viable but also economically and geographically feasible, owing to specific factors (Hadjidemetriou et al. 2018):

- Unified management oversees all distributed energy resources (DERs) and loads.
- Proximity and connection of loads and DERs within a shared network.
- Connection of the campus to the primary utility grid at a shared coupling point (PCC).

The HOMER software, created for distributed power applications, has been selected as the optimization tool for this study due to its widespread use in renewable energy endeavors. HOMER software's selection for this research is rooted in its comprehensive microgrid optimization capabilities and its wide acceptance and use in various global studies, including those in South Africa (Motjoadi et al. 2022). HOMER is acclaimed for its adeptness at managing intricate aspects of optimal power system design by considering a diverse range of resources, numerous configurations, and various other parameters (Perera et al. 2013). In the South African context, HOMER has played a pivotal role in numerous studies. For instance, a case study on the design and simulation of a grid-tied power supply system using HOMER for Lebowakgomo, South Africa was presented by Motjoadi

Fig. 1 A roof-mounted solar PV at DUT

et al. (2022). The study aimed to tackle challenges that the South African power grid network faces, such as frequent power failures and load shedding. They proposed integrating renewable energy sources, like solar and wind, with battery systems to offer additional power sources and backup batteries during downtimes. HOMER software was used to simulate and analyse the most viable techno-economic option for the Lebowakgomo community. The study found a blend of energy systems such as solar PV, wind turbine, national grid inclusion, diesel generators, and battery systems integrated with converters as the most feasible choice. This method can decrease reliance on the national grid while ensuring a dependable and sustainable power supply to the community, highlighting the potential benefits of integrating renewable energy sources with battery systems in addressing power interruptions and load shedding in South Africa (Motjoadi et al. 2022).

This paper's primary contribution is suggesting an optimal hybrid power system for a university campus microgrid, taking into account technical, economic, and environmental factors. The proposed microgrid model pursues two objectives: maximizing annual utility bill savings and minimizing CO_2 emissions. HOMER ranks simulation outcomes based on net present cost (NPC), with the lowest value representing the best configuration. However, this study takes both objectives into account when recommending the optimal configuration for the case study in question. The remainder of the paper is organized as follows: section "Methods" outlines the methodology, including the case study details and the modeling of hybrid renewable energy system (HRES) components. Section "Results" presents and discusses the simulation results, while the conclusions are shared in the final section.

Methods

Description of the case study

Universities in South Africa are connected to the national grid operated by ESKOM, which primarily generates electricity from aging and unreliable coal-fired power stations. This has led to frequent load shedding across the country and has impacted the grid's reliability. Consequently, consumers, including residential, industrial, and commercial sectors, are increasingly seeking renewable energy sources. Universities are also exploring alternative energy sources during load shedding, with some installing solar PV on building rooftops, although these installations are often not integrated to meet the university's total electrical load demand. As a result, the importance of both grid-connected and off-grid hybrid power systems on university campuses is growing. The University of KwaZulu-Natal (UKZN) was established in January 2004 after merging Natal University and the University of Durban-Westville. UKZN operates five campuses in two major cities in KwaZulu-Natal province: Durban and Pietermaritzburg. These campuses include Edgewood Campus, Nelson Mandela Medical School Campus, Howard College Campus (Fig. 2), Pietermaritzburg Campus, and Westville Campus. UKZN serves over 46,000 students across these campuses in various undergraduate and postgraduate programs. This study used the Howard College Campus as a case study. The campus offers programs in Science, Environmental, Engineering, Management Studies, Humanities, Law, and Social Sciences. The aerial view of the campus, situated on a hill, reveals a significant area covered with buildings that have potential for solar PV panel installation. Additionally, the campus has vacant land that could accommodate a solar PV farm on the order of 10 MW.

Fig. 2 Aerial of Howard college campus (UKZN. "Campuses." 2020)

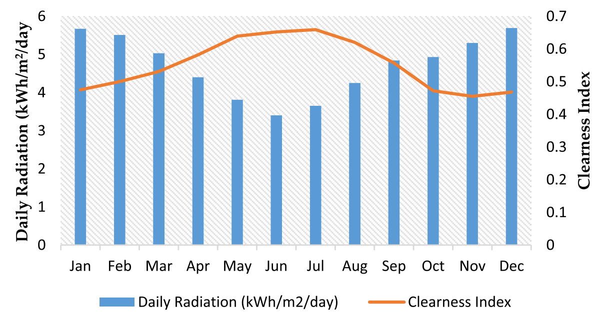


Fig. 3 Global horizontal irradiance, Durban

Weather data of howard college campus

University campuses are a promising platform for the deployment of renewable energy source (RES) to meet energy demand, minimize carbon footprints on campus and can be characterized as a smart city. The meteorological data for the campus as seen in Figs. 3 and 4 were acquired from NASA website. The annual mean wind speed and yearly average temperature for Durban were

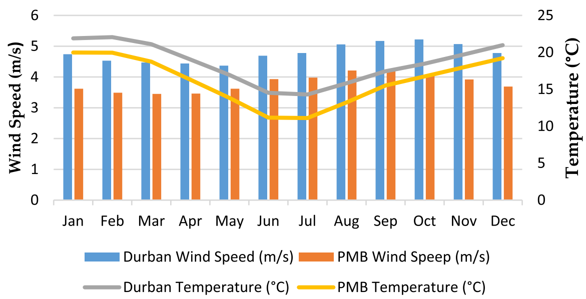


Fig. 4 Wind speed and temperature, Durban and Pietermaritzburg

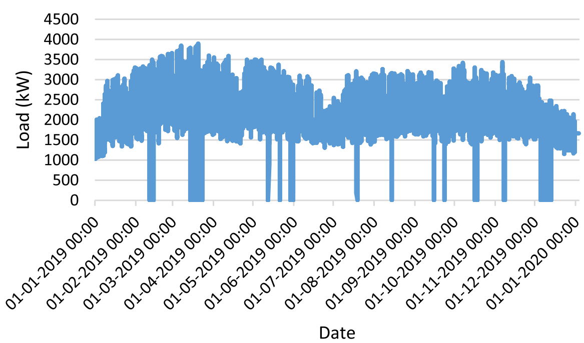


Fig. 5 Howard College Campus load profile

4.78 m/s and 18.53 °C respectively while the annual mean global horizontal irradiance (GHI) was 4.71 kWh/m^2/day.

Load data

Energy demand on the university campus defers depending on academic disciplines; for example, engineering and science departments are equipped with experimental facilities and heavy machinery that consume a substantial amount of power. Also, the campus has student residences that contribute to the entire campus load inform of lighting, heating, cooking. Other loads include electronics (computers, printers, photocopiers) and air-conditioning (Leal Filho et al. 2019). The real-time load data used for the simulation in HOMER was downloaded for smart energy meters installed on the campus. Figure 5 shows the half-hourly load data for 2019. The total energy consumed on the campus for 2019 was 18.84 GWh.

Tariff structure

The Howard College campus at the University of KwaZulu-Natal is linked to the national power grid through the eThekwini electric system, which employs a time-based pricing structure (TOU) (IRENA 2019). This approach allows users to control power usage manually or automatically, reducing expenses. The cost of electricity varies based on the hour and season, enabling the utility company to apply different rates during high- and low-demand periods, encouraging consumers to adjust their power consumption to less busy times (IRENA 2019). The timeframes for the time-based pricing during the summer season (low demand, September 1 to May 31) and the winter season (high demand, June 1 to August 31) are presented in Fig. 6, with Table 1 showing the corresponding charges (eThekwini, "19, 20 Tariff booklet," e. 2020) Despite the availability of various customizable rate options in HOMER, the eThekwini electric TOU pricing plan was integrated into the HOMER software's library and utilized for the simulation (eThekwini, "19, 20 Tariff booklet," e. 2020).

Modelling of HRES components and techno-economic analysis with HOMER

A schematic diagram of a typical hybrid power system consisting of several components such as RES (hydro, solar, wind) energy storage system (battery, flywheel, supercapacitor), bidirectional converter (inverter), conventional energy source (utility grid, diesel generator), etc. is shown in Fig. 7. The mathematical modelling of some components used in this paper are described below, while the parameters of the HRES microgrid components is given in Table 2

Photovoltaic (PV) panel

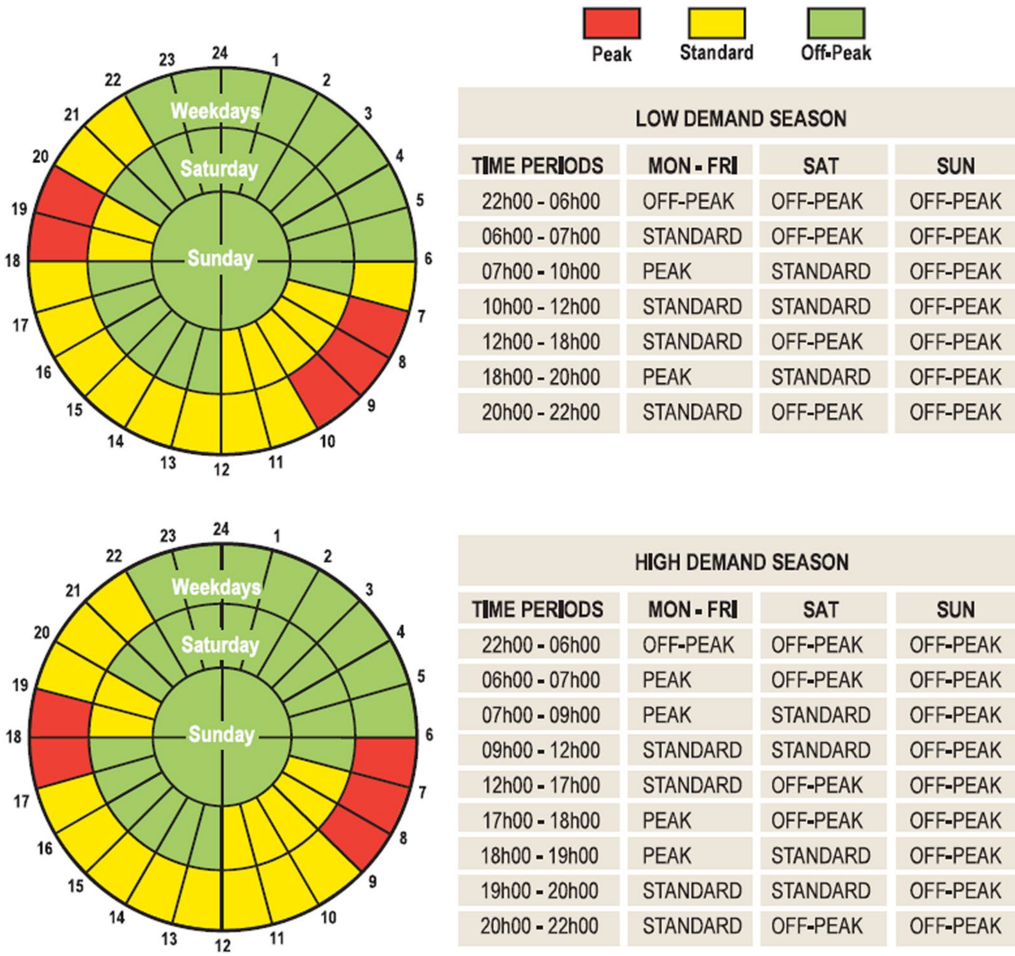
Photovoltaic panels or arrays are employed to generate electrical energy by converting solar radiation into electrical power. The hourly energy generated by the PV panel can be calculated from Eq. (1) (Adefarati et al. 2019; Kaur et al. 2020).

$$P_{PV} = C_{PV} D_{PV} \left(\frac{I_T}{I_{T,STC}} \right) [1 + \alpha_P (T_C - T_{C,STC})] \tag{1}$$

The rated capacity of the PV panel or array is represented by C_{PV} (kW), while the derating factor of the PV array (in %) is denoted by D_{PV}. I_T refers to the solar radiation incident on the PV array (kW/m^2) at the current time step, and α_P is the temperature coefficient of power (%/°C). The solar radiation under standard test conditions (1 kW/m^2) is indicated by $I_{T,STC}$, while TC is the PV cell temperature (°C) and $T_{C,STC}$ signifies the PV cell temperature under normal test conditions (25 °C). The PV panels have a lifespan of 25 years, and no tracking system is installed. If the temperature effect on the PV array is disregarded, meaning the temperature coefficient of power is considered zero, the Eq. (1) can be modified as follows:

$$P_{PV} = C_{PV} D_{PV} \left(\frac{I_T}{I_{T,STC}} \right) \tag{2}$$

HOMER incorporates the derating factor to account for factors like cable losses, panel dirt accumulation,



LOW DEMAND SEASON			
TIME PERIODS	MON - FRI	SAT	SUN
22h00 - 06h00	OFF-PEAK	OFF-PEAK	OFF-PEAK
06h00 - 07h00	STANDARD	OFF-PEAK	OFF-PEAK
07h00 - 10h00	PEAK	STANDARD	OFF-PEAK
10h00 - 12h00	STANDARD	STANDARD	OFF-PEAK
12h00 - 18h00	STANDARD	OFF-PEAK	OFF-PEAK
18h00 - 20h00	PEAK	STANDARD	OFF-PEAK
20h00 - 22h00	STANDARD	OFF-PEAK	OFF-PEAK

HIGH DEMAND SEASON			
TIME PERIODS	MON - FRI	SAT	SUN
22h00 - 06h00	OFF-PEAK	OFF-PEAK	OFF-PEAK
06h00 - 07h00	PEAK	OFF-PEAK	OFF-PEAK
07h00 - 09h00	PEAK	STANDARD	OFF-PEAK
09h00 - 12h00	STANDARD	STANDARD	OFF-PEAK
12h00 - 17h00	STANDARD	OFF-PEAK	OFF-PEAK
17h00 - 18h00	PEAK	OFF-PEAK	OFF-PEAK
18h00 - 19h00	PEAK	STANDARD	OFF-PEAK
19h00 - 20h00	STANDARD	STANDARD	OFF-PEAK
20h00 - 22h00	STANDARD	OFF-PEAK	OFF-PEAK

Fig. 6 Tariff plan (eThekwini, "19, 20 Tariff booklet," e. 2020)

Table 1 Energy charges

Season	Peak	Energy charges (R/kWh) Standard	Off-Peak
Summer	1.12	0.80	0.54
Winter	3.24	1.04	0.61

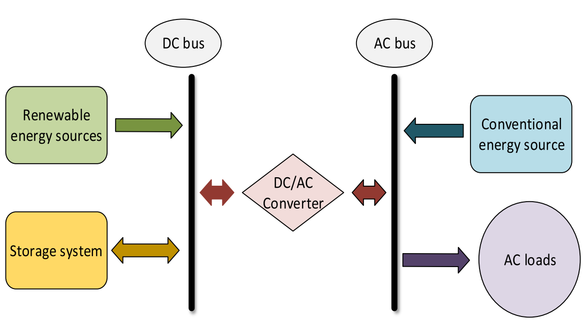


Fig. 7 A typical block diagram of HRES

shading, aging, and snow coverage. Solar PV producers determine their modules' power output using standard test conditions (STC), which include 1 kW/m^2 irradiance, a cell temperature of 25 °C, and no wind. However, these standardized testing conditions do not represent typical operational scenarios, as cell temperatures under full sunlight often exceed 25 °C (HOMER, "HOMER 2020).

Wind turbine (WT)

Wind turbines are designed to convert rotational kinetic energy into electrical energy. The mechanical power produced by a wind turbine is proportional to the blade area (A) in square meters, the wind velocity (V) in meters per second at hub height, and the air density (ρ) in kilograms per cubic meter. Equation (3) is used to calculate the power generated by a wind turbine (Feroldi and Zumoffen 2014; Akhtari and Baneshi 2019).

Table 2 Parameters of the HRES microgrid components

System component	Description	Capital cost (R)	Replacement cost (R)	O & M cost R/year	Operating lifetime (Year)	Other details
PV	Fronius Symo 20.0-3-M	35,000	35,000	700	25	Efficiency:7.3% Operating Temp: 45 °C Capacity: 5 kW
Wind turbine	Norvento nED 24	1,000,000	1,000,000	20,000	20	Capacity:100 kW Hub height:36 m
Diesel generator	Generac 100 kW	250,000	250,000	250	15,000 h	Minimum load: 30%
Battery	Lead Acid (ASM)	16,000	16,000	160	5	Initial SOC:90% Min SOC: 40% Max charge current: 167 A Max discharge current: 500 A Nominal Capacity (kWh):1.03 Maximum Capacity (AH):513
Power converter	System Converter	30,000	30,000	300	15	Efficiency: 95% Relative capacity: 100

$$P_{wind} = \frac{1}{2}\rho A V^3 \tag{3}$$

HOMER relies on the wind turbine's power curve to compute an estimate of the rated wind turbine power output at that wind speed, under normal temperature and pressure conditions. HOMER remarkably increases the power value expected by the power curve by the air density ratio, by using Eq. (4) to calculate the performance of the wind turbine, P_{WT} in kW.

$$P_{WT} = \left(\frac{\rho}{\rho_0}\right) P_{WT,STP} \tag{4}$$

In this context, $P_{WT,STP}$ refers to the wind turbine's output at standard temperature and pressure in kilowatts, while ρ symbolizes the actual air density (kg/m^3), and ρ_0 denotes the air density at maximum temperature and pressure (1225 kg/m^3), respectively.

Diesel generator (DG)

Diesel generators are often incorporated into hybrid power systems, especially for off-grid applications or islanding situations, to address the intermittency of renewable energy sources and enhance system reliability by compensating for power shortfalls. A diesel generator is composed of a diesel engine and a control system. The correlation between the power output of a single diesel engine, $P_{\text{engine}}(t)$, and its fuel consumption at a given time t, $V_{fuel}(t)$ in liters per hour, can be determined by Dawoud et al. (2018).

$$V_{fuel}(t) = \alpha + \beta P_{engine}(t) \tag{5}$$

In this context, α signifies the no-load fuel consumption in liters per hour, and β denotes the relationship between diesel fuel and power output in liters per kWh. HOMER assumes a linear function for the fuel curve. Equation (6) demonstrates the connection between the diesel generator's fuel consumption, F in liters per hour, and its electrical power output in kilowatts.

$$F = F_0 Y_{gen} + F_1 P_{gen} \tag{6}$$

In this case, F_0 refers to the intercept fuel curve coefficient (liters per hour per kilowatt), F_1 indicates the slope of the fuel curve (liters per hour per kilowatt), Y_{gen} represents the estimated diesel generator power (kW), and P_{gen} stands for the diesel generator's electrical output (kW) (HOMER, "HOMER 2020).

Techno-economic analysis and optimization with HOMER

The success of any hybrid power system project relies on accurate economic analysis and technical design. Technical design involves precise sizing of hybrid system components to meet demand throughout the year. HOMER software (Pro and Grid) is extensively used by researchers, project managers, and investors as an optimization tool for modeling and analyzing hybrid power systems. The objective is to minimize electricity costs by reducing demand charges and optimizing the use of available renewable energy sources at the site, ultimately reducing greenhouse gas emissions. The project's economic viability is evaluated using key financial performance indicators (FPIs) such as net present cost (NPC), cost of energy (COE), internal rate of return (IRR), payback period (PBP), and return on investment (ROI) (Gu et al. 2018). In this study, HOMER Grid (Pro Edition) was employed to simulate the proposed hybrid power system. HOMER ensures an energy balance between power sources and load demand for each hour of the year (8760 h) during the simulation. Essentially, it compares the total load (thermal and electrical) for a given hour to the available system energy for that hour and makes decisions accordingly. For systems that include storage elements (like batteries or fuel cells) or diesel generators, HOMER decides at each hour whether to discharge or charge the storage and whether to run the generators (HOMER, "HOMER 2020; NREL, "HOMER 2004). HOMER uses two optimization algorithms: an initial search algorithm that simulates all feasible system structures within the search space and a proprietary derivative-free algorithm that finds the most cost-effective system. HOMER then provides a ranked list of setups and configurations, starting with the lowest net present cost (NPC) or lifecycle cost, allowing for comparison between various system design alternatives (Olatomiwa et al. 2015). HOMER accounts for unforeseen factors, including uncertain input parameters such as interest rates, inflation rates, fuel prices, solar radiation, and wind speed. Sensitivity analysis is conducted by defining these variables before optimization. Multiple values for each variable are entered, and HOMER repeats the optimization process for each sensitivity variable. Value, demonstrating how the results are affected. (HOMER. HOMER 2020). Sensitivity analysis was not carried out in this work.

Results

The HOMER Grid software simulation results, including the base case (grid only) and five hybrid systems, are presented in Table 3. The optimal hybrid configuration for the HC campus is a Photovoltaic–Wind Turbine–Diesel Generator–Grid (PV–WT–DG–G), with a Net Present Cost (NPC) of R375,167,800, a Cost of Energy (COE) of R1.044, and annual utility bill savings of R15,668,490. This configuration also has the lowest CO_2 emissions among the assessed systems, amounting to 5805.2 tons/year. The existing system's annual energy purchased is 18,857,939 kWh, which is close to the actual smart meter reading of 18,842,623 kWh. With the optimal hybrid system in place, the annual energy purchased drops to 9,218,890 kWh, and with net metering, the net energy purchased is only 3,100,567 kWh. The investment details, such as the payback period of approximately four years and an internal rate of return (IRR) of 24.83%, are summarized in Table 3. Figure 8 showcases the monthly utility bills for the current system and the proposed hybrid system, while Fig. 9 illustrates the cumulative cash flow over the project's 25 year lifespan.

Discussion

Table 3 provides a comprehensive comparison of the base case and five hybrid systems, highlighting the optimal PV–WT–DG–G configuration that maximizes utility bill savings and minimizes CO_2 emissions. This configuration

Table 3 Simulation results for Howard College Campus

Economic metrics	Base case	WT–DG–G	PV–WT–DG–G	WT–DG–B–G	PV–WT–G	WT–G
Payback (years)	N/A	3.9	4.0	4.1	4.0	3.9
COE (R/kWh)	1.932	1.044	1.044	1.084	1.047	1.048
IRR (%)	N/A	25.2	24.83	23.91	24.78	25.16
NPC (R)	523 447 300	374 855 300	375 167 800	382 357 200	376 294 700	375 957 300
Annual utility bill saving (R)	N/A	15 579 110	15 668 490	15 435 600	15 559 530	15 472 240
Environmental metrics						
CO_2 emissions (metric ton/yr)	11 918.20	5 827.90	5 805.20	5 895.00	5 804.9	5 827.6
Annual fuel consumption (l/yr)	N/A	610	617	616	N/A	N/A

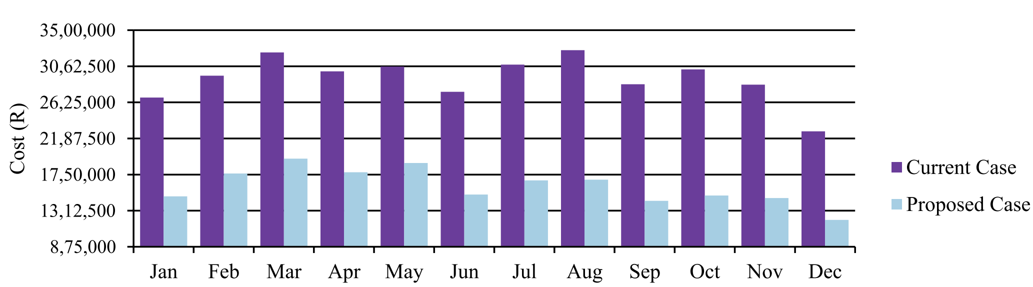


Fig. 8 Utility Bills (monthly)

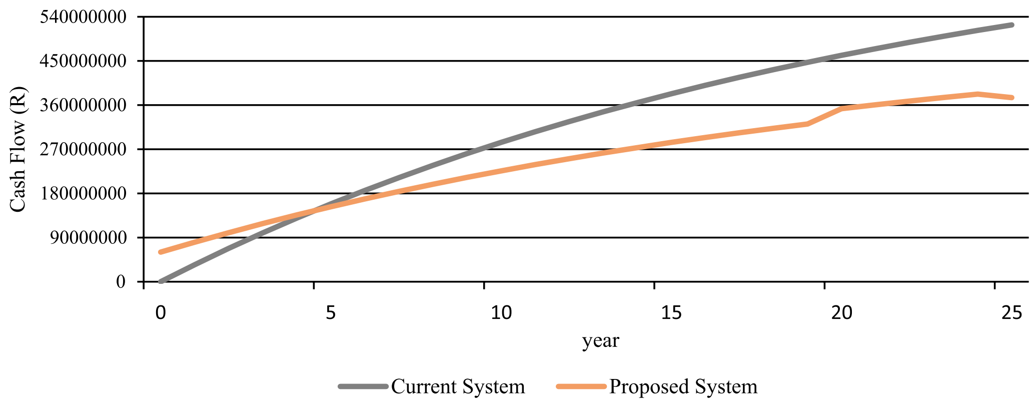


Fig. 9 Cumulative cash flow

Table 4 Summarized energy charges

	Consumption charge	Demand charge	Fixed rate	Total
Base case	R29.2 M	R5.74 M	R54,000	R35.0 M
Proposed case	R13.9 M	R5.33 M	R54,000	R19.3 M
Annual savings	R15.3 M	R413,154	R0.00	R15.7 M

suggests the addition of 135 kW of solar power, 100 kW of generator capacity, and 59 kW of wind generation capacity, which would decrease the annual utility bill to R19.3 million.

Figure 8 clearly demonstrates the cost savings achieved by implementing the optimal hybrid configuration compared to the current system, indicating its effectiveness in reducing the monthly utility bills for the campus. The figure also emphasizes the benefits of utilizing the PV–WT–DG–G configuration, as it offers the same COE as the WT-D-G setup but provides greater savings and reduced emissions.

Figure 9 offers insights into the long-term financial viability of the project, as it displays the cumulative cash flow for the entire 25 year lifespan. The figure supports the claim that the optimal hybrid system can generate a positive return on investment, with a payback period and IRR presented in Table 3. The data in Table 4 emphasizes the financial attractiveness of the PV–WT–DG–G configuration, indicating a relatively short payback period and a high IRR, making it a favorable choice for the campus. The results also show that the current system relies heavily on grid connection, while the proposed hybrid system can substantially reduce the energy purchased from the grid, resulting in significant savings and environmental benefits.

The findings from Table 3, Figs. 8 and 9 have significant policy implications for the promotion of renewable energy and hybrid systems in educational institutions and beyond. These implications include:

Financial incentives: Policymakers should consider providing financial incentives, such as grants, tax credits, or feed-in tariffs, to encourage the adoption of renewable energy and hybrid systems like the PV–WT–DG–G configuration. The demonstrated cost savings and reduced emissions make these systems an attractive and environmentally responsible choice.

Energy transition targets: The results highlight the potential for renewable energy and hybrid systems to contribute to a country's energy transition targets. Policymakers should integrate these systems into their national and regional energy plans, setting ambitious goals for renewable energy generation and CO_2 emissions reduction.

Grid infrastructure and regulations: The findings emphasize the need for updated grid infrastructure and regulations to accommodate renewable energy and hybrid systems. Policymakers should invest in grid modernization and formulate supportive regulatory frameworks that promote grid interconnectivity, energy storage, and smart grid technologies.

Educational institutions as role models: Given the demonstrated benefits of the PV–WT–DG–G configuration in the campus setting, educational institutions can serve as role models for the broader community by adopting renewable energy and hybrid systems. Policymakers should encourage such institutions to lead by example, showcasing the potential for clean energy solutions to reduce costs and minimize environmental impacts.

Capacity building and knowledge transfer: Policymakers should support the development of human resources and skills required to design, implement, and maintain renewable energy and hybrid systems. This may include promoting relevant educational programs, research, and industry partnerships that foster innovation and knowledge transfer in the renewable energy sector.

Conclusion

An in-depth technical, economic, and environmental assessment of an optimized hybrid power system for a college campus has been conducted. This research proposes an ideal configuration that maximizes the use of distributed energy resources (DERs) to reduce reliance on the utility grid, leading to significant savings. The findings indicate that incorporating DERs into the campus energy mix can considerably lower energy costs and CO_2 emissions. The savings on utility bills can be reinvested into on-campus renewable energy initiatives, such as installing solar panels on all buildings and investing in energy storage. This strategy would also decrease the expenses associated with diesel generators used as backup during power outages. Considering the frequent power outages affecting South Africans recently, it is essential to explore off-grid hybrid power systems for college campuses to achieve self-sustainability during load shedding. The impact of load shedding on university operations is immense, as it can disrupt lectures, laboratory experiments, office comfort, and internet connectivity across the entire campus. In light of these challenges, future research will focus on investigating suitable hybrid power systems for off-grid applications within a university setting.

Abbreviations

CO_2	Carbon dioxide
COE	Cost of energy
C_{PV}	Rated capacity of the PV panel or array
DERs	Distributed energy resources
DG	Diesel generator
DPV	Derating factor of the PV array
DUT	Durban University of Technology
ESKOM	Electricity Supply Commission (South African primary electricity supplier)
GHI	Global horizontal irradiance
GHG	Greenhouse gas
HOMER	Hybrid optimization model for multiple energy resources
HRES	Hybrid renewable energy system
HC	Howard College (as in the context, though not explicitly stated)
IRR	Internal rate of return
IT,STC	Solar radiation under standard test conditions
kWh	Kilowatt-hours
NASA	National Aeronautics and Space Administration
NPC	Net present cost
NZEB	Nearly zero energy buildings
PBP	Payback period
PCC	Point of common coupling
PV	Photovoltaic
PV–WT–DG–G	Photovoltaic–wind turbine–diesel generator–grid
PWT	Performance of the wind turbine
R	Rand (South African Currency)
RES	Renewable energy source
RESs	Renewable energy systems
ROI	Return on investment
SDGs	Sustainable development goals
SOC	State of charge
STC	Standard test conditions
STP	Standard temperature and pressure
TOU	Time of use
UKZN	University of KwaZulu-Natal
V	Wind velocity

Acknowledgements
Not applicable.

Author contributions
Author KTA: Paper conceptualization, literature review, and methodology development, initial data analysis. Author DREE: Data analysis, results interpretation, and draft revisions, final editing and proofreading of the paper, checking for consistency, accuracy, and adherence to the journal's formatting and citation guidelines. Both authors have read and approved the manuscript.

Funding
Authors are grateful to Durban University of Technology for funding this research.

Availability of data and materials
Not applicable.

Declarations

Ethics approval and consent to participate
Not applicable.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

Received: 11 April 2023 Accepted: 27 May 2023
Published online: 31 May 2023

References

Adefarati T, Adefarati T, Obikoya GD (2019) Techno-economic evaluation of a grid-connected microgrid system. Int J Green Energy 16(15):1497–1517. https://doi.org/10.1080/15435075.2019.1671421

Akhtari MR, Baneshi M (2019) Techno-economic assessment and optimization of a hybrid renewable co-supply of electricity, heat and hydrogen system to enhance performance by recovering excess electricity for a large energy consumer. Energy Convers Manag 188:131–141

Dawoud SM, Lin X, Okba MI (2018) Hybrid renewable microgrid optimization techniques: a review. Renew Sustain Energy Rev 82:2039–2052

Dehghanmongabadi A, Hoşkara Ş (2018) Challenges of promoting sustainable mobility on University Campuses: the case of Eastern Mediterranean University. Sustainability. https://doi.org/10.3390/su10124842

Elenkova MZ, Papadopoulos TA, Psarra AI, Chatzimichail AA (2017) A simulation platform for smart microgrids in university campuses. In: 52nd International Universities Power Engineering Conference (UPEC), Heraklion, Greece, 28–31 Aug 2017, no. Conference Proceedings. https://doi.org/10.1109/UPEC.2017.8231998.

eThekwini, "19/20 Tariff booklet", e. E. Unit, 2020

Feroldi D, Zumoffen D (2014) Sizing methodology for hybrid systems based on multiple renewable power sources integrated to the energy management strategy. Int J Hydrogen Energy 39(16):8609–8620

Gu Y, Zhang X, Myhren JA, Han M, Chen X, Yuan Y (2018) Techno-economic analysis of a solar photovoltaic/thermal (PV/T) concentrator for building

application in Sweden using Monte Carlo method. Energy Convers Manag 165:8–24
Hadiyanto A, Ambariyanto YJ, Utama P, Maryono S (2018) Managing campus energy: compromising between rapid needs and environmental requirement. E3S Web of Conf. https://doi.org/10.1051/e3sconf/20183101003
Hadjidemetriou L et al (2018) Design factors for developing a university campus microgrid. In: IEEE International Energy Conference (ENERGYCON), Limassol, Cyprus, 3–7 June 2018, no. Conference Proceedings. https://doi.org/10.1109/ENERGYCON.2018.8398791
Hasapis D, Savvakis N, Tsoutsos T, Kalaitzakis K, Psychis S, Nikolaidis NP (2017) Design of large scale prosuming in Universities: the solar energy vision of the TUC campus. Energy Build 141:39–55
HOMER, "HOMER GRID Local User Manual" 2020
HOMER. HOMER GRID Local User Manual (2020)
IRENA, "Innovation landscape brief: time-of-use tariffs", Abu Dhabi 2019
Kaur M, Dhundhara S, Verma YP, Chauhan S (2020) Techno-economic analysis of photovoltaic-biomass-based microgrid system for reliable rural electrification. Int Trans Electr Energy Syst. https://doi.org/10.1002/2050-7038.12347
Leal Filho W et al (2019) A comparative study of approaches towards energy efficiency and renewable energy use at higher education institutions. J Clean Prod. https://doi.org/10.1016/j.jclepro.2019.117728
Makkonen H, Tikka V, Lassila J, Partanen J, Silventoinen P (2013) Green campus-energy management system
Motjoadi V, Kilimi MG, Bokoro PN (2022) Design and simulation of grid-tied power supply system using HOMER: a case study of Lebowakgomo in South Africa. In: 2022 30th Southern African Universities Power Engineering Conference (SAUPEC). IEEE, pp 1–9
NREL, "HOMER: the micropower optimization model", National Renewable Energy Laboratory, Colorado, USA, 2004
Olatomiwa L, Mekhilef S, Huda AN, Sanusi K (2015) Techno-economic analysis of hybrid PV–diesel–battery and PV–wind–diesel–battery power systems for mobile BTS: the way forward for rural development. Energy Sci Eng 3(4):271–285
Perera A, Attalage R, Perera K, Dassanayake V (2013) Designing standalone hybrid energy systems minimizing initial investment, life cycle cost and pollutant emission. Energy 54:220–230
Rebelatto BG, Lange Salvia A, Reginatto G, Daneli RC, Brandli LL (2019) Energy efficiency actions at a Brazilian university and their contribution to sustainable development Goal 7. Int J Sustain High Educ 20(5):842–855. https://doi.org/10.1108/ijshe-01-2019-0023
Salvia AL, Brandli LL (2020) Energy sustainability at universities and its contribution to SDG 7: a systematic literature review. In: Leal Filho W et al (eds) Universities as living labs for sustainable development: supporting the implementation of the sustainable development goals. Springer International Publishing, Cham, pp 29–45
Tu Q, Zhu C, McAvoy DC (2015) Converting campus waste into renewable energy—a case study for the University of Cincinnati. Waste Manag 39:258–265. https://doi.org/10.1016/j.wasman.2015.01.016
Tu Q, Zhu C, McAvoy DC (2015) Converting campus waste into renewable energy–a case study for the University of Cincinnati. Waste Manag 39:258–265
UKZN. "Campuses". https://ukzn.ac.za/about-ukzn/campuses/. Accessed 16 Nov, 2020
Vourdoubas J (2019) Energy consumption and carbon emissions in an Academic Institution in Greece: can it become carbon neutral. Stud Eng Technol. https://doi.org/10.11114/set.v6i1.4013

Publisher's Note

Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Submit your manuscript to a SpringerOpen journal and benefit from:

- ► Convenient online submission
- ► Rigorous peer review
- ► Open access: articles freely available online
- ► High visibility within the field
- ► Retaining the copyright to your article

Submit your next manuscript at ► springeropen.com